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Does agrivoltaism reconcile energy and agriculture? Lessons from a French case study

Romain Carrausse[1*] and Xavier Arnauld de Sartre[2]

Abstract

Background Agrivoltaism is presented as an innovative production system that may combine agricultural activity and energy production on the same parcel of land. The deployment of this innovation has already begun in France as part of the energy transition initiatives, and many actors consider that its deployment only depends on social acceptance issues. However, given that agrivoltaism cuts across the agricultural and energy sectors, social, technical, and political concerns have arisen. While these concerns are primarily reflected in conflict and opposition, the problem goes far beyond the simple question of social acceptance. Indeed, it relates to the dynamics of innovation and governance, structured in different arenas at different scales that shape how this innovation is deployed.

Methods The authors conducted a qualitative study revolving around three methodological approaches: a press analysis, a review of scientific literature, and fieldwork in the Pyrénées-Atlantiques district in France. Drawing on the case of a disputed project, several semi-structured interviews were conducted. These interviews explored how the public sector, institutions, energy companies, and local farmers perceive the development of agrivoltaics and how they organise the dynamics of governance to control its deployment.

Results Our analysis highlights four main results: (i) agrivoltaism is an innovation conceptualised in techno-scientific arenas which seek to define its agricultural viability; (ii) at the national level, the remote control by the State does not provide a framework for governance capable of involving the various actors in the fields of agriculture and energy; (iii) the deployment of agrivoltaism systems across regions engenders conflict while placing key local actors in a situation of uncertainty with regard to how best to manage this innovation; (iv) while individuals are subjected to territorialisation, this paradoxically favours structural policy innovations which outline the contours of territorial governance.

Conclusions This study shows that agrivoltaism is the result of interactions between techno-scientific actors in the energy and agricultural fields. However, its political backing in France does not promote dynamics of governance capable of bringing these two fields together. At the local level, the deployment of agrivoltaism has faced opposition, but it has also led to the organisation of territorial governance strategies involving actors and institutions from different sectors.

Keywords Agrivoltaism, Territorialisation, Governance, Techno-scientific trajectory, South-West of France

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Background

Within the wide range of renewable energy production technologies that harness solar energy, agrivoltaism is now being deployed in different regions as part of an energy transition initiative. It is a system of production that aims at combining agricultural activity and energy production through the use of solar panels on the same plot of land [1]. Several agrivoltaics's systems exist: from simple photovoltaic panels above livestock farms, to vertical and bifacial panels suitable for field crops, to dynamic agrivoltaics, where the panels are remotely controlled according to the shading needs of the plant. The key technical challenge is to find the balance between sufficient electricity production for the panels to be profitable, and ensuring that the shading effect of these panels does not affect the crops in question [2]. This issue is most of the time considered as not being a problem anymore, since agrivoltaism deployment is supposed to face mainly social acceptance issues [3].

In fact, most of the literature on agrivoltaics aims to demonstrate that agrivoltaics is beneficial to farmers [4–7]—so it is not really an issue of social acceptance. In Scopus, only two papers address social acceptance of agrivoltaism. Torma and others studied farmers' perceptions of agrivoltaics [8]. They look at perceptions of agrivoltaics to prevent land use conflicts, as they believe this innovation has a high potential to address land use conflicts. Hu, on the other hand, takes a critical view of agrivoltaics [9]. He shows that in China agrivoltaics has been introduced following green development strategies—a situation that must have led to conflicts, but without studying such conflicts. However, the logic of conflicts around agrivoltaics deployment, the actors who oppose agrivoltaics, and the ways in which "perceptions" of agrivoltaics become conflictive have not, to our knowledge, been explored by any author.

The problem, however, goes far beyond the simple question of benefits for farmers, or even of social acceptance, and has now become an issue of how regulate the use of this technology. The fact that agrivoltaism cuts across both the agricultural and the energy sector may not be taken for granted. Indeed, articulating such different sectors raises social, technical, and political challenges. These challenges often arise during the implementation phase and manifest themselves via opposition and conflict. Indeed, in addition to reflecting the concerns associated with the impact of technology, conflict and opposition reveal the shortcomings of the political regime's construction of a technology that originated and was developed without considering how it would be implemented at the local level nor, more broadly, how it would be incorporated within the existing regimes.

The focus of this paper is threefold: (i) to what extent does the development and spread of agrivoltaism result from connecting and coordinating the energy and agricultural fields in different arenas at different scales? (ii) How can we qualify the agrivoltaism management framework in France and how far is it capable of bringing together actors in the energy and agricultural sector? (iii) To what extent does this history of agrivoltaism contribute to conflict and makes it difficult for actors at the local level to adopt this innovation?

This study drew from *sustainable transitions studies* [10], complemented by studies from *geography sustainability transitions* [11] and recent works on social acceptance issues [12]. As a result, we conducted a multidimensional and dynamic analysis of the interactions between actors that structure the different forms of management of agrivoltaism [13]. We therefore associate the following three arenas: the techno-scientific arena which is behind the deployment of the technology; the national governance level, i.e. the level that makes it possible to provide a framework; and the local level, i.e. the level involving the implementation of the innovation. Each arena was analysed based on a different corpus: an analysis of the scientific literature for the techno-scientific arena, an analysis of the press and of a report produced by the Agency for Ecological Transition (ADEME) in France at the national level, and an analysis of a case study at the local level. This case study, conducted in the South-West of France (Pyrénées-Atlantiques district), shows that the development of agrivoltaism tends to consider the local scale as among the last constraints to be got over. It also reveals the desire to provide a framework for this technology, which may have led its development to be viewed differently. While the conflicts that arise because of the implementation of this production system show that social acceptance is one of the obstacles to its implementation, this obstacle more broadly relates to political backing at different scales and to the structuring of the dynamics of dialogue and negotiation between the actors of different regimes. These elements raise further debate in the context of technology usage.

The second section presents our theoretical and methodological approach. The third section, "Results and interpretations", discusses the main results relating to our three initial questions. The last section, "Discussions", revisits these results and proposes avenues to develop this work further and recommendations that may make meaningful contributions to the theories used.

Methods

Qualifying agrivoltaism—Sustainable transition studies and geography sustainability transition: considering modes of governance in social acceptability of renewable energy technology

Agrivoltaism can be considered as a technological innovation that aims at combining two productive systems, the agricultural and the energetic. At first glance, this innovation can be considered through the lens of *Technological Innovation System* (TIS) approaches [14], which provide an interesting opportunity to grasp of this innovation aims at combining two productive systems in the same regime. Regarding our study, three main elements emerge from these theories.

The first relates to the challenges of deploying technology, summarised in the TIS framework referred to as the *Multi-Level Perspective* (MLP) and based on the path that an innovation must follow to be deployed, not only should it be technically viable; it may also fit within existing regimes, without excessively disrupting them, succeed in building its own regime and becoming part of what this approach refers to as the "landscape" [15]. The second element of interest relates to the components of an innovation system that makes it possible to shift from one level to another. A new technology must be able to interact with existing infrastructure, but should also be supported by actors, notably institutions, to enable it to find its path within the existing systems or to compose its own system. Lastly, this theory considers that a new technology must meet the challenges present at different levels: the production and dissemination of knowledge; entrepreneurial experimentation; influence on the research directions; market formation; legitimacy; resource mobilisation; and the development of positive externalities [14].

TIS makes it possible to provide a complex vision on the way agrivoltaism combines two regimes. Nevertheless, these theories have been criticised for not putting sufficient emphasis on a political perspective [16]. Indeed, they are thought to pay insufficient attention to the power struggles between actors leading to the development of frameworks conducive to the deployment of a new technology, and to the spatial and scalar dimension in the deployment of technologies and socio-technical transition processes [10]. The path that technologies have to find according to the MLP theory is socially constructed by the actors of innovations: a technology can be deployed only if the actors that support it find for them a place in the markets (by defining a niche for it or by negotiating subsidies for its initial deployment), if they adapt legal framework to its characteristics (no existing legal framework fits naturally to a new technology), if they find places where to deploy them—in other words, if they build, within arenas [16], a governance that may allow its deployment. In the case of agrivoltaism, the issue is to build a new governance system that conceals the energy and the agricultural sectors, each of them having its own rules and inherent interests.

For these reasons, social acceptance of a new technology (moreover, in our case, when this technology conceals two productive regimes) goes far beyond the reaction of inhabitants impacted by the project. This is what the "third wave of social acceptance literature" [12] now hypothesises. Summarising thirty years of study of social acceptance, S. Batel considers that three waves of work on social acceptability of renewable technology have succeeded; the question of governance has been a central point of these approaches for the last two [12, 17]. During the second wave, the work shows the importance of modes of governance in the conflictuality of technology through questions of distributive or procedural justice in the governance of the projects. The researchers of the third wave emphasise the different modes of governance of renewable energy technology (RET) [18], and consider that the oppositions to RET are most of the time oppositions to the system that supports them: they go far beyond problems of governance to shed light on the way innovations are conceived before being deployed. This is why invited participation misses, most of the time, its objectives: because it does not take into account the citizen wills when conceiving the technologies [19]. These results are in line with those on the question of citizen participation or deliberative turn, particularly in the French case of the energy sector [20, 21]. The way French energy governance is organised and the weight of technocentric and centralising actors explain the obstacles to a decentralised and participatory energy transition. For example, the delays in the development of offshore wind energy in France can be explained by the absence of regulations and a way to deploy the technology that does not allow them to be adapted to the environment and territorial context [22–24].

This is why our study needs, in order to understand how agrivoltaism is being deployed, to be based on the study of the way the assembling of technologies has been framed by its promoters, particularly the policy-makers and the scientists that developed and supported agrivoltaism. More broadly, since agrivoltaism aims to reconcile agriculture and energy, the question of the policy regime [25] from which the technologies are deployed is central here, particularly with regard to the modes of governance deployed to reconcile these two sectors. This multiscalar approach focuses on the actors, power relationships, institutions and modes of governance that shape the government of a problem or a cross-sectoral technology [26]. As with the work on offshore wind power, the

Table 1 Number of actors interviewed, names of structures, type of actors, mode of interview, duration and dates

#	Structure name	Type of actors	Mode	Duration	Date
1	Domaine Nidolères	Farmer	Face to face	1h23	November 2021
2	French Agrivoltasm	Association	Face to face	1h15	November 2021
3	Sun'Agri	Company	Face to face	1 h	November 2021
4	Land prospector	Autoentrepreneur	Web Conference	1h36	November 2021
5, 6, 7, 8	Chamber of Agriculture of the Pyrénées-Atlantiques region	Public institution	Face to face	1h30	February 2021
9, 10	La Campagnotte	Farmer and energist	Face to face	2h40	February 2021
11	Réseau Transport Electrique	Public service company	Web conference	1 h	February 2021
12	Peasant Confederation	Farmer union	Face to face	1h30	February 2021
13	Directorate General in charge of Territories and the Sea in the Pyrénées-Atlantiques region	Deconcentrated state services	Face to face	1h25	February 2021
14	ENEDIS	Public service company	Web Conference	1 h	February 2021
15	Energy Regulatory Commission	Independent authority	Web Conference	50 min	February 2021
16	The urban community of Pau	community	Face to face	1 h	February 2021

political dimension of a technology can be read through this approach by analysing the instruments that frame it [27], the characteristics of its territorialisation [28], those of its narration [29], and the territorial governance that regulates it [30]. To analyse the modes of governance related to agrivolatism, we adopted a dynamic approach to the modes of governance of socio-technical transitions and their innovations: these political processes consider objects and actors at different scale levels and lead to the creation of new arenas of governance [13, 22, 30].

Briefly summarised, this analytical framework helped us to consider the deployment of agrivoltaism, in its reconciliation of the energy and agricultural regime, at the social, political, and technical level, through the structuring of the dynamics of governance in different arenas.

Literature review and semi-structured interviews

In order to analyse how agrivoltaism is governed in different arenas, we adopted two methodological approaches. First, we undertook a literature review of scientific articles published about agrivoltaism. We analysed all the scientific literature on the SCOPUS database using the keyword "*agrivoltaic*". Following recent semantic stabilisation in this field, we identified 39 articles in march 2021. Of these, only one addressed agrivoltaism from any dimension other than the technical one [3]. We also drew on two other literature reviews [2, 31]. The analysis of the scientific literature provided us how agrivoltaism is legitimised and developed at a global level, in the techno-scientific sector. It is from the year 2018 that the number of publications becomes significant (more than 10 per year), which can be explained in particular by the organisation of the first-world congress on agrivoltism in 2020 in France. The United States, France and Malaysia are the three most prolific countries in terms of publication. Dufour and Marrou, two French scientists who proposed the term agrivoltaism in 2012, and Othman, a Malaysian researcher, were the most published authors at the time. We will see in the next section that the analysis of the experiments at work, the partnerships on which the scientific work is based, their actors, provide information on the modes of governance that support this innovation.

Our second methodological approach focused on conducting interviews with 16 actors located primarily in the Pyrénées-Atlantiques region, presented in Table 1. This fieldwork was undertaken after our scientific literature review. Three strategies were thus privileged: the first was to meet actors involved in an agrivoltaic project in Denguin, an area close to the Pau region (64); the second was to meet key local actors concerned with questions raised about the development of agrivoltaism in the region; the third was to meet major public and private actors in the development of agrivoltaism in France. In contrast to our analysis of the scientific literature at the global scale, these interviews were conducted with the objective of analysing the actors and modes of governance at work in the deployment of an agrivoltaic project at the local scale. These interviews were conducted between February and November 2021. We conducted semi-directive interviews structured around 6 themes: (i) scientific work and technical issues of agrivoltaism; (ii) actors and institutions involved in the development of this technology; (iii) issues and economic models of agrivoltaism; (iv) factors of concern and support; (v) planning schemes and instruments related to agrivoltaism; (vi) the link between this technology, the climate change and the energy transition issues.

Results

We have divided this section into three parts that correspond to the main results of analysis relative to the mode of governance at work in the deployment of agrivoltaism. First, we analyse the way agrivoltaism has been framed by the scientists who developed this solution. Second, we show how the French state translated this assembling in its own terms in order to prepare its deployment. In both arenas, we show that agrivoltaism is conceived as a way to reconcile agriculture and energy through a specific policy instrument, the call for tender. In the third part, we analyse the consequences of this framing when the assembling of technology is being deployed in a particular situation, through the study of the deployment of an agrivoltaic chicken breeding farm in the South-west of France (located in the Pyrénées-Atlantiques district). Doing so, we aim at showing that the conflictuality and governance issues at the local level of agrivolatism stem in part from the way this technology is governed and deployed at the national and international levels.

Reconciling energy and agriculture: the prism of a socio-technical construction

In this section, the analysis of the development of agrivoltaism in the techno-scientific sector shows that it is a technology from the energy regime seeking to align itself with the agricultural regime.

From emergence to experimentation: a model of knowledge production focused on the agricultural viability of agrivoltaism

It was at the Solare Energie systeme (ISE), the largest European structure for industrial research on solar energy, that the first work on what would become agrivoltaics appeared. In 1981, A. Goetzberger and A. Zastrow suggested a configuration on the same plot of land of a solar power plant on stilts and agricultural production at ground level [32]. They addressed an issue that would later become a key concern—the model of production and dissemination of knowledge—which even today influences the direction of research on agrivoltaics: how does the shading of photovoltaic panels affect crops? This question reveals the relationships between both technologies: energy production is supposed not to affect too much agricultural production.

Addressing the agrivoltaics' issue from the perspective of reconciling agricultural and energy production is still a key concern of many scientific studies on the issue. This explains why the knowledge production model is characterised by partnership research between energy companies and research institutes specialising in agronomic issues. It seeks to experiment with different types of crops and different solar panel technologies in diversified geographical contexts. The United States, Europe, and East Asian countries are the key actors influencing research orientations and France holds a prominent position because of the Sun'Agri research program. This program is the result of a partnership between the French National Research Institute for Agriculture and the Environment (INRAE) and the economic player, Sun'R, which specialises in solar energy. In 2011, its researchers proposed the name "agrivoltaics", the first semantic formalisation of this production system [1]. Building on the ISE research in the hope of commercial development in the future, the research program is experimenting with dynamic agrivoltaics, a technical device where photovoltaic panels are mobile and monitored remotely using software to follow the path of the sun. This system's objective is to increase electricity production and the solar radiation available to plants [33, 34].

From experimentation to legitimisation: creating narratives about the positive externalities of agrivoltaism

The diffusion of knowledge through experiments on agrivoltaics led to the creation of narratives about its technical viability in terms of reconciling energy and agricultural production. In particular, the technical legitimacy of agrivoltaics is demonstrated through the winning combinations of the shade produced by the photovoltaic panels and its positive externalities for the crops on the ground. Its potential, in terms of crop productivity, is proven when the associated crops are shade-tolerant. Its legitimacy is also based on its positive economic externalities: an increase in farm value compared to a conventional farm—up to 30% in the United States [35]. Another argument in its favour is that it increases national renewable energy production—again, in the U.S. case, if the lettuce crop alone is converted to an agrivoltaic system, the photovoltaic power would increase from 40 to 70 gigawatts, i.e. the entire national production in 2015 (*ibid*). Finally, all the available results show that the legitimacy of the use of agrivoltaics is closely linked to the geographical context: because of their intense heat or sunshine, certain climatic regions are more favourable than others to shaded crops.

The fact that the legitimisation of agrivoltaics is based on its viability in coupling energy production and agricultural production shows that it is an innovation coming from the energy sector. Indeed, while major advances have been made in solar panel technology—particularly dynamic solar panels—its reconciliation and viability with agricultural production has progressed at a much slower rate. For this reason, research studies have focused on the impact of shading on the productivity of the crops in question, the types of crops experimented with, the

shading characteristics applied to them, and the geographic area of experimentation. Yet, many uncertainties remain about the effects of shading across crop types, the long-term consequences of shading, the reversibility of farms using this type of practice, or the geographic areas suitable for deployment [2, 36, 37].

Agrivoltaism has been conceptualised, experimented with and promoted at the global level. It has been carried out within techno-scientific arenas. Analysing its trajectory reveals, on the one hand, the framework that guided experimentations relating to agrivoltaism, and on the other hand, how these frameworks shaped the creation of narratives about this innovation and the types of actor coalitions behind its development. The tension inherent in this system of production lies in the reconciliation of the energy and the agricultural regimes, which is left—for now at least—to the territories' discretion. The insufficiency in the construction of an appropriate instrument and mode of governance at the national level to reconcile the actors and interests of two regimes, energy and agriculture, is the subject of the next section.

The government's remote monitoring of the use of agrivoltaics: call for tenders, institutionalisation, and land tenure issues in France

In this section, we analyse the way that French policymakers adopted and adapted a framework that aims to conciliate energy production and agriculture to French case.

Governing by call for tenders to achieve quantified objectives: the French policy of RET

The political backing for agrivoltaism is not different of the way the French government conceive the transformation of energy regime when including renewable energy technologies. Indeed, the Multi-Annual Energy Plan (PPRE)[1] launched by the French State gives objectives for RET production, but does not construct a policy neither narrative for the RET production. Agrivoltaism is perceived as a means of achieving the objective set by the PPRE in terms of photovoltaic production.

As in the case of wind power [22], remote governance characterises how the deployment of this technology is managed by the State [38]. This mode of governance is visible in the Energy Regulatory Commission's (ERC) call for tenders concerning "the realisation and operation of innovative electricity production facilities from solar energy". This call was set up by the ERC in 2017. Since then, there have been three calls, during which the specifications have been modified. While there were to be nine winners in the first period, the distribution of the call for tenders changed in the second period, i.e. in 2019. There are now two types of tenders: the first focuses on innovative ground-mounted photovoltaic installations, and the second on innovative photovoltaic installations on buildings or parking lot shades, or innovative agrivoltaics' installations. In this second type, 21 projects were awarded in 2019, and 31 in 2020. The call for tenders has been used to provide a framework for the development of agrivoltaics in terms of time and quantity. Since 2017, the overall volume awarded has increased each year. In June 2018, this mechanism allowed agrivoltaics to receive more sustained support from the State. Sébastien Lecornu, then Secretary of State, organised discussions among stakeholders to boost renewable energy nationwide. This dialogue led to the decision to increase by 30% of the volume of agrivoltaics in the energy mix set by the PPRE.

The deployment of agrivoltaics through the mechanism of calls for tenders is a very centralised and opaque mode of State governance which overlooks the territories: it defines objectives and funds the deployment of the technologies, but without defining a specific policy for agrivoltaism. The assessment of a what a photovoltaic project should be is not proposed by the call for tenders: the technical criteria determining whether it should be registered as an agrivoltaic production system remains in the hands of the ERC and the Directorate General for Energy and Climate (DGEC) evaluators. Indeed, as an ERC actor mentioned: "The Ministry defines the main criteria on which innovative projects should be assessed (…) but it is becoming impossible to specify, a priori, in the specifications, what is or is not an innovation". This lack of definition of what agrivoltaism should be put a particular emphasis on the energy part of the assembling, since its objectives are above all defined in terms of energy production objectives.

Land tenure issues reveal the importance of energy objectives in agrivoltaism

The CRE's call for tenders is an instrument that attempts to provide a framework for the deployment of agrivoltaics within the energy regime, but it does not reconcile it with the agricultural regime. Land tenure issues reveal the difficulties that agrivoltaics faces in reconciling these two regimes: on the one hand, this innovation allows the energy sector to respond to these issues in order to meet the PPRE objectives; on the other hand, this interest in scarce land is a source of concern for the agricultural sector.

One of the main narrative's accompanying agrivoltaics is its low risk of land use conflicts. In particular, the

[1] The PPRE predicts that, by 2028, the photovoltaic capacity will rise to between 35 and 44 gigawatts. In 2020, this capacity stood at 10 gigawatts.

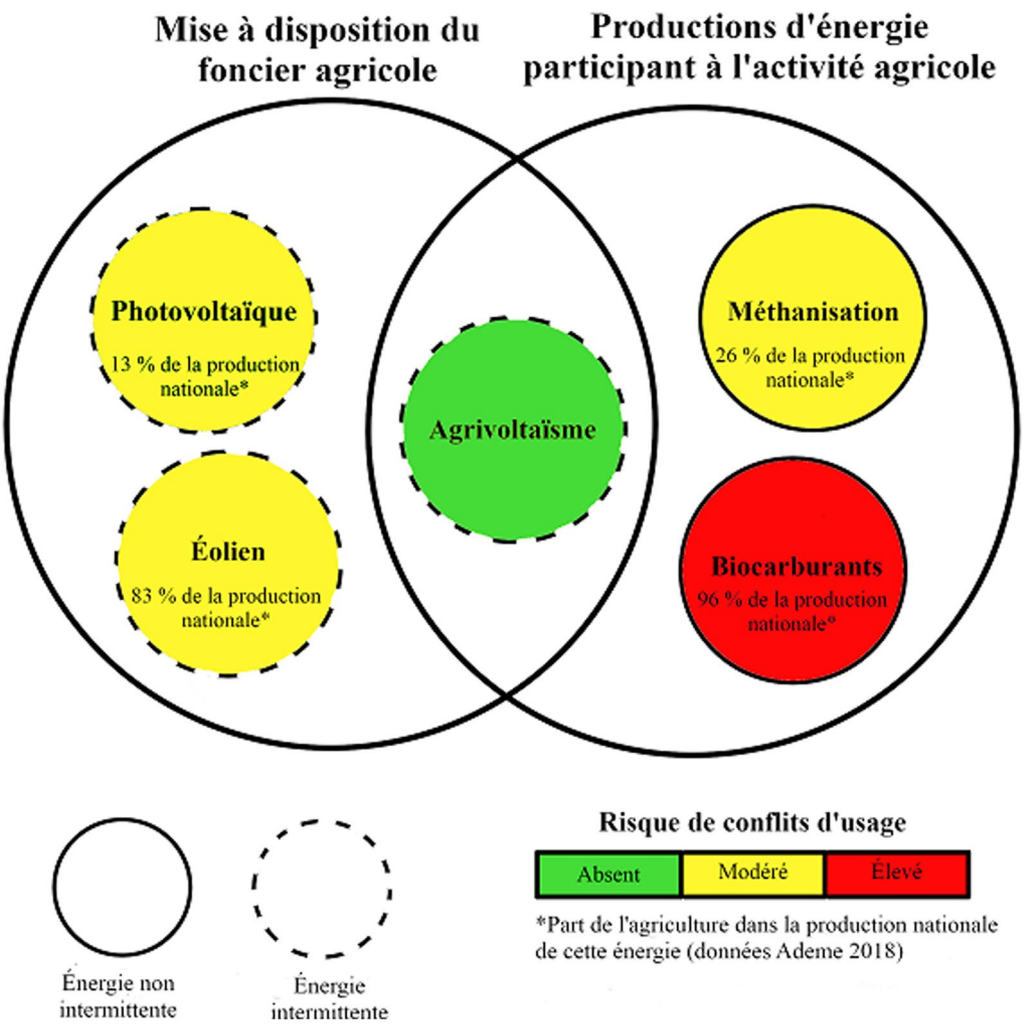

Fig. 1 Typology of sources of energy in the agricultural sector and the risk of conflict relating to their use [39]

energy regime considers that the land efficiency of this production system legitimises its suitability for the agricultural regime. At the political level, a parliamentary report entitled "*L'agriculture au défi de la production d'énergie*" [39], suggests that agrivoltaics is the technique with the least risk of land use conflicts—as illustrated in Fig. 1: "Typology of sources of energy in the agricultural sector and the risk of conflict relating to their use" and by the translation of this figure in Table 2 and considers it as a virtuous model for both farmers and producers of renewable energy (RE). Considering this low risk of land use conflicts, agricultural issues are not addressed at any time in this document, and more generally during the first times of political works on agrivoltaism.

Nevertheless, there are many concerns about agricultural, that raised around land issues. An article in *Le Monde*, published in March 2021, confirms the fears or misconceptions that agrivoltaics can generate with regard to its promise of the efficient use of agricultural land: "Behind this recent term, which is supposed to bring together initiatives aimed at reconciling both agricultural uses and electricity production, there is currently a very wide variety of practices. ADEME intends to propose precise and operational criteria for the development of the sector. And safeguards to avoid abuse and windfall effects" [40]. In the face of these concerns, there have been no regulation attempts at the national level to reconcile the land issues of these two systems.

Left without any political instruments, and excluded from consultations involving stakeholders at the national level, agricultural sector actors have taken strategic ownership of this issue in order to strengthen their bargaining power with the stakeholders of the energy sector. This is illustrated by the charter between EDF Renouvelables, the Assemblée Permanente des Chambres d'Agriculture (APCA), and the Fédération Nationale des Syndicats

Table 2 English translation of figure a; Source: Authors

Mise à disposition du foncier agricole	Availability of agricultural land
Production d'énergie participant à l'activité agricole	Production of energy involved in agricultural activities
Photovoltaique	Photovoltaic
13% de la production nationale	13% of the national production
Eolien	Wind turbine
83% de la production nationale	83% of the national production
Méthanisation	Methanogenesis
26% de la production nationale	26% of the national production
Biocarburants	Biofuels
13% de la production nationale	13% of the national production
Risque de conflits usage	Risk of conflict relating to their use
Absent–Modéré–Elevé	Absent–Moderate–high
Energie non intermittente	Non-intermittent energy sources
Energie intermittente	Intermittent energy sources
Part de l'agriculture dans la production nationale de cette énergie (données Ademe 2018)	Percentage of agriculture in the national production of this energy (Source: ADEME, 2018)

d'Exploitants Agricoles (FNSEA), which refers to arbitration on the use of agricultural land by photovoltaic projects to the territorial level [41]. The reconciliation of the energy and agricultural regimes, which leads to the escalation of tensions because of the land issue, is not the subject of regulation nor of a specific policy. This issue is addressed at the level of territorial governance.

Institutionalising for better deployment: turning to ADEME to define the criteria for reconciling energy and agriculture

While no instruments have been developed to address the land issues associated with agrivoltaics, the State proposed a clear definition of what agrivoltaism should be through one National Agency, the ADEME.[2] This is an attempt to institutionalise agrivoltaics to enable actors to evaluate the projects proposed in response to national and territorial calls for tenders.

In the report published by the agency, both qualification and attention criteria have been established to define agrivoltaics. ADEME has retained the service provided to agricultural production as the most important criterion: "The service provided by photovoltaic panel technology to agricultural production seems to us to be the most important criterion to define agrivoltaics. In fact, the role of agrivoltaics is closely linked to the notion of synergy and therefore of service. (…) Therefore, it seems to us that the nature of the service(s) rendered by the coupling must be studied to define agrivoltaics" [42]. Agriculture is then reincorporated in agrivoltaism definition.

Different levels of services are retained, from a direct or indirect service at the plot level to other services such as the perpetuation of the farm or access to additional land (ibid). Based on these criteria, ADEME defines the synergy that should characterise an agrivoltaic project at three levels: first, where the project provides services to agricultural production at the plot level; second, where the synergies are both at the level of services rendered to agriculture at the plot level, but also at the farm level in terms of economic income; and a third level where the first two are complemented by an agronomic synergy, i.e. an improvement in agricultural production in terms of both quality and quantity.

A first definition of agrivoltaics is then proposed: "Agrivoltaics characterises the influence of photovoltaic modules on agricultural production in the field on the same plot of land, by directly providing one of these services: adaptation to climate change, access to protection against hazards, improvement of animal welfare, specific agronomic services meeting the needs of the crops; and this without inducing either a significant degradation of agricultural production or a decrease in income from agricultural production, unless if the overall income of the farm is improved" (*ibid*).

The process of the institutionalisation of agrivoltaics must take into account the extent to which the reconciling of energy production and agriculture is adequate. The fact that the definition revolves around agricultural issues confirms once again that agrivoltaics derives from the energy sector and seeks agricultural viability. Moreover, there is a conspicuous absence of social or political

[2] The ADEME is the national agency for ecological transition, a public institution with an industrial and commercial nature (EPIC) under the supervision of the Ministries of Ecological Transition and Territorial Cohesion, of Energy Transition and of Higher Education and Research. It aims to "accelerate the transition to a more sober and supportive society".

debate. Instead of building a policy framework for agrivoltaism that would have aimed to reconcile since the beginning energy and agriculture, the French state used the instrument of calls for tender to encourage the deployment of agrivoltaism, basing its deployment only on energy production objectives. It is only in a second phase that it tried to define what agrivoltaism should be incorporating agricultural objectives. The absence of a balanced national framework for the deployment of agrivoltaism led, that will be the third part of our paper, to failures in the deployment of the first projects.

When agrivoltaism becomes reality: the rejection of an energy solution by the agricultural sector in the South-West of France

In this section, we analyse how the history of agrivoltaism, both as an innovation and as it has been framed by the French government, explains the failure of the development of a specific project in the South-West of France.

A case study on different registers of opposition to an agrivoltaic project: from land issues to agricultural legitimacy

An agrivoltaic project located near the town of Denguin in the Pyrénées-Atlantiques district has been the subject of media attention and of two types of opposition. The project is now cancelled. One of these opposition was expected: it came from the neighbouring of the site. Nevertheless, the project also faced opposition coming from the agricultural sector and was not supported by the administration.

This project was an "experimentation of solar shading in a free-range chicken run" on an eight-hectare plot of land housing 16,000 chickens [43]. It was judged innovative enough by the CRE to be winner of the second round of the CRE's call for tenders on "innovative solar energy" in 2017. In this area, chicken farming is uncommon compared to cereal farming. The land was previously owned by a cereal farmer who had installed an irrigation perimeter. Therefore, this project is representative of the implementation of the French agrivoltaism policy: he is governed at distance by the State with the call for tenders; it has not been the subject of a local participation; livestock breeding is one of the most widespread agricultural activities in agrivoltaism in France. The project was made public during the administrative procedures with the local authorities in 2020. Soon afterwards, a collective of local residents came together to oppose the project and grabbed media attention [44–46]. Through on-site demonstrations and the creation of a petition on change.org, this opposition from the local population was accompanied by a conservative narrative that revolved around three dimensions: landscape impact, olfactory pollution, and devaluation of the surrounding real estate: "If such an installation were to be built, it would cause olfactory, noise, and visual pollution, and our living environment would be impacted! It would also significantly reduce the value of the local real estate market." However, the project leaders defended agrivoltaics on the grounds of its modernity: "Experimenting with a new agricultural method that respects the environment, improves animal welfare and generates new income for farmers"; "Contributing to the energy transition and fighting against climate change" (agri-solaire, *op.cit*). Viewed from this modernist narrative, opposition from the locals was disqualified as conservative, as evidenced by the words of one of the project's initiators: "I find it very difficult to carry out my project because it is very innovative. (…) Actually, the most virulent argument is 'not in my backyard' you know, it's this philosophy of saying, 'I am afraid of being bothered and I especially do not want change next to me'."

This kind of opposition is quite normal when a new project arrives in a specific locality. But the promoters of the technology did not anticipate oppositions coming from the agricultural sector itself. Indeed, the representatives of the agricultural sector also opposed the project and constructed a conservative narrative based on different dimensions. The land issue was at the centre of the conflict. Surprisingly, both the Confédération Paysanne and the Chambre d'Agriculture were opposed to the project with regard to this issue.[3] The eight hectares that the project targeted consisted of arable, cereal, and irrigated land. The president of the Chamber of Agriculture said that they could not "let eight irrigated and reconsolidated hectares with strong agronomic and cultural potential be used for mere energy production". Another point of contention related to the price of land purchase. An offer beyond the initial asking price was made, which the agricultural sector's actors interpreted as proof that agrivoltaics would upset the land-economy model of the sector. In short, they believed that the generous offer was made possible only because of the income that would be generated by the electricity production component of the project. This was confirmed by one of the project leaders: "Of course, today when you are an energy company, it is very easy financially to go and rent land for 150 euros a year, and you even want to give five times more (…) but yes, there's this emotion in the agricultural world, that's it." The land issue as a whole exacerbated the conflict

[3] The Chambre d'agriculture are composed by elected representatives of farmers that defend their interest at a department scale (there are 98 deparments in France). In most of the cases, the representatives come from the FNSEA, majority union among the farmers, while the Confederation paysanne is the minority union and most of the time opposed to the FNSEA and the agricultural chambers.

between the project holders and the opponents, in terms of severe conflict. Finally, the agricultural legitimacy of the project was questioned by both the Confédération Paysanne and the Chamber of Agriculture. For the former, agricultural activity was not one of the project's priorities: "Right now, the purpose is to sell energy, not to produce chicken. I think producing chicken is what you need to be doing to get authorisations. (…) What we criticise is that these projects are not, in fact, at the service of agriculture, they are just windfall effects." For the latter, the agricultural legitimacy of the project holders posed a problem: "Our priority is that, if we have to defend or accompany an agri-photovoltaic project, it must be with real farmers. In this case, they are not farmers."

From uncertainties to ownership issues: local policy in the face of forced territorialisation

Beyond the conflictual issue of agrivoltaics in the territories illustrated by this case study, the Denguin project revealed a second dimension: that of a forced territorialisation of agrivoltaics. In other words, remote control by the State through the instrument of calls for tenders led to the deployment of agrivoltaics in the territories, while key local actors were faced with many uncertainties relating to how to regulate this new production system.

The first point of uncertainty arose from the lack of clear regulation and the incomplete institutionalisation of agrivoltaics, even though it was to be deployed in the territories. The evaluation of a project was left in the hands of the local administration and the local officials. One actor from the Pau-Béarn-Pyrénées agglomeration testified that: "(…) I have the impression, if you will, that, particularly with the CRE call for tenders, agrivoltaics is arriving on the territory (…) even before the local authorities or the various institutions have had the time to establish strategies around this, to train themselves on this subject". He further spoke of the uncertainty they faced in assessing the agricultural vocation of projects: "That's the difficulty: it's an assessment, and the assessment of the definition can be subjective (…) So we are starting to think that we have to learn to understand this new technology". A representative of the Chamber of Agriculture illustrated it in these terms: "I think that we have put the cart before the horse".

The second point was related to the previous one. In terms of incorporating agrivoltaics as a regulated activity, the instruments usually used in spatial planning strategies at the territorial level were incompatible. Planning instruments such as the Local Inter-municipal Plans (PLUI) stipulate that ground-mounted power plants are prohibited on agricultural land. However, agrivoltaics is designed differently from a ground-mounted power plant because of its synergy between energy production and agriculture. A member of the *Direction Départementale des Territoires* (French Department of Territories) explained it thus: "The principle is mentioned in an urban planning document: 'no photovoltaic construction on agricultural land'. The thing is, the regulations *can* authorise constructions and installations as long as they are not incompatible with the exercise of agricultural activity. (…) So how do we manage compatibility?" The lack of regulation on this subject did not allow the existing instruments to incorporate this type of activity in their nomenclature. According to a player in the local agglomeration, this was a characteristic feature of new technologies in the field of energy transition: "We can see that in the field of energy transition in general, we have been constantly adapting the rules for the past ten years, and there are always experiments that put their foot in it and make the rules change or stay the same."

The third element of uncertainty expressed by local actors relates to the fact that agrivoltaism was assumed to be technically immature. Once again, there were signs of a sudden territorialisation, as expressed by an actor from the Chamber of Agriculture: "I think that we have to be very careful (…) Having this explained without any hindsight is a little more difficult to accept." This view of a lack of techno-scientific maturity was shared by the urban area agent: "we are not sufficiently mature on this. We don't have enough control over the impacts of this type of power plant on a site like this." Viewing agrivoltaics as technically immature also allowed the agricultural sector to assert its power in the game of political arbitration at the local level: "(…) we have the impression that the agricultural world is being dispossessed, even though it is the owner of the land today". That reveals that agrivoltaics does not really bring together two sectors: in this case, the agricultural sector did not wish to support the project. Moreover, the governance at work at the local level did not reconcile the interests of actors from different sectors. The conflictual nature of the Denguin project is one of the direct consequences of this.

The early phases of territorial governance: the first signs of a "bottom-up" territorialisation

The uncertainties of local public action and power issues between the actors in the face of forced territorialisation contributed to the beginnings of territorial governance with regard to agrivoltaics. The local policy revealed, through different points, how the territory took strategic ownership of this new production system.

The early warning signs relating to the ownership of this subject were observed among the local policy actors. An actor from the Pau-Béarn-Pyrénées urban area said: "The idea is to ponder over the type of framework that will allow us to define the future of agrivoltaics. (…) And

we are working on this with the Chamber of Agriculture and that means that we will be able to easily map the potential sites." The president of the Chamber of Agriculture also explained this process of taking strategic ownership: "Our commitment and our concern is right there: No plain land. (…) Hence the decision of the Chambers of Agriculture of the Nouvelle-Aquitaine region and the Chamber of Agriculture of the Pyrenees-Atlantique district to be favourable to the development of photovoltaics in places where, indeed, there is abandonment, where there is no agricultural production, or little, very little." This notion of strategic ownership is also present in the words of an actor from the Confédération Paysanne agricultural union: "When we see that there are proposals to couple agricultural production with electricity production by photovoltaic panels on the ground, we are not opposed to it, we look at it carefully, but we do not want agriculture to be an alibi for energy production."

The second point concerns the structuring of local public action through the formation of stakeholder coalitions representing the various sectors concerned. The objective of this structuring is to define a territorial strategy on agrivoltaics and to guide the projects. On this issue, one actor from the urban area of Pau said: "I think that we must have the two main actors on this subject: the Chamber of Agriculture which is the guarantor of good agricultural activity, and the territories which are the prescribers and authorisers of what happens on their territory. The president of the Chamber of Agriculture also illustrates that coalitions of actors are being formed in order to provide a territorial framework for the development of agrivoltaics: "It is our mission today, at the Chamber of Agriculture, to establish bridges and to build partnerships so that we, the agricultural world, can share our expertise, and energy experts, their photovoltaic expertise."

The structuring of local public action was achieved through two instruments relating to two arenas of negotiation between the stakeholders of agrivoltaic projects: the *Commission Dépatementale des Préservation des Espaces Naturels, Agricoles et Forestiers* (Departemental Commission for the Preservatin of Natural, Agriculturel and Forest Areas) and the *Commission Opérationnelle des Projets* (COP). The COP involves innovations at the organisational level in order to respond to the operational challenges posed by renewable energies and agrivoltaics to deconcentrated services, such as those already observed in the restructuring of the regional services of the Ministry of Ecology [47]. An actor from the state administration in charge of agriculture (DDTM) in the Pyrénées-Atlantiques district presents this original idea: "The problem with renewable energies is that each actor exposes its point of view about what concerns them without necessarily seeing how others interact with the regulations. (…) As a result, we asked the Préfet[4] to create this instance: on the one hand we created the pole of Renewable Energy (RE) in the Pyrénées-Atlantiques district (…) and we created this commission which is an initiative of the RE department (…) This makes it possible for project holders to come and present their projects and to have a regulatory framework (…) but also to learn about the territorial, geographical, political context. (…) Because interpretation varies according to the political context, there can be a different sensibility from one department to another." Key local actors are finding ways to take strategic ownership of agrivoltaics and to deploy it across territories. These are the first signs of the structuring of governance which, as well as featuring subdued territorialisation, territorialises agrivoltaics "from the bottom".

Discussion

This article has analysed the trajectory of agrivoltaism, from its conceptualisation to its deployment across regions. The focus was on three main questions: (i) to what extent does the development and spread of agrivoltaism result from connecting and coordinating the energy and agricultural fields in different arenas at different scales? (ii) how can we qualify the agrivoltaism management framework in France and how far is it capable of bringing together actors in the energy and agricultural sector? (iii) to what extent does this history of agrivoltaism contribute to conflict and makes it difficult for actors at the local level to adopt this innovation? Three main results must be highlighted that explain the difficulties of the deployment of agrivoltaics and shed light on how innovations straddling the energy and agriculture sector are developed, managed, and territorialised.

First, in this combining of technologies, the agricultural and energetic sectors are not equivalent. This has been evidenced in the three arenas we studied. As a scientific and technical innovation, agrivoltaism has been experimented with in techno-scientific arenas to establish its technical viability and, more particularly, its agricultural viability. The results of these experiments have led to the creation of narratives about this innovation relating to the positive externalities for agriculture and to the effective use of land, made possible by the reconciliation of two types of production on the same plot. This techno-scientific knowledge legitimises and makes agrivoltaism viable. However, this legitimisation conceals uncertainties about the

[4] The Prefet is the representative of the French republic president at a department scale.

potential negative externalities of this innovation. Moreover, these experiments cannot hide the fact that neither sector is equal: the objective of the experiments is to avoid too much impact on agriculture production, not to conciliate them. At the national scale, the State's decision to entrench agrivoltaism in CRE tenders reveals the decision to have this innovation governed within the energy regime. However, the land issue has escalated tensions in attempts to reconcile the energy and agricultural regimes. The way agrivoltaics may articulate with the agricultural sector has only been questioned when the deployment of agrivoltaics faced limitations. Our case study in the South-West of France confirmed the lack of articulation with agricultural production, the project being proposed by newcomers in agriculture that ensured the rentability of their chicken breeding project associating it with energy production. These tensions have led to the emergence of two phenomena: the first is that actors in the agricultural sector have taken ownership of this issue in order to negotiate conditions for its deployment at the regional level; the second involves ADEME's institutionalisation of this innovative production system in order to establish technical criteria for defining it.

Second, our result also highlights one specific way of developing renewable energy technologies in France and its consequences. Agrivoltaics is managed through calls for tenders, a way for the state to impulse innovation. But it is done without articulating with the territories, their necessities, and then creates difficulties not only with the neighbouring, but also with the incumbent actors and, this is more surprising, within the state administration itself.

Third, our analyses show that the lack of social acceptance of agrivoltaics appears as the consequence of the lack of institutionalisation of this combining of technologies rather than inherent in the population themselves. The absence of a participatory governance process that reconciles the interests of the agricultural and energy sectors at different scales explains the conflict and the difficulties of local public action in the face of the agrivoltaic project. Indeed, at the local level, the territorialisation of agrivoltaism is being coerced. The case study conducted in the Pyrénées-Atlantiques district shows that it has been a source of conflict reflected in opposition to the local population and resistance from the agricultural sector. Beyond the potential conflict, key local actors are uncertain about the framework to provide for this innovation on a regional scale- and consequently they are not able to support the deployment of the project.

Conclusions

The trajectory of agrivoltaism shows how the energy sector is experimenting with innovative production systems that grant access to agricultural land for fulfilling energy transition objectives. The State's remote control has led to the absence of any genuine political framework at a national level, between different regimes, for this type of innovation. The fact that deployment in the territories has taken place even before the institutionalisation process has been finalised has fuelled the conflict relating to this type of technology, and placed policy actors in a situation of uncertainty regarding how best to relate these innovations to the region. Territorialisation, to which actors are subjected, paradoxically promotes organisational changes that allow policy actors to take strategic ownership of these new production systems and to outline the contours of territorial governance.

Several points for discussion arise with regard to our findings. (i) The first is that a comparative approach with other spatial contexts may help to improve the generalisability of our conclusions and case study. Indeed, while our study reveals how the spatial and scalar dimension influence an innovation's framework, and how the dissemination of this innovation involves a socio-technical transition process, it would be interesting to compare these results with those obtained in different contexts in order to understand the differences and similarities. (ii) Moreover, comparing other projects in different territorial contexts may provide an opportunity to take stock of different modes of governance that structure agrivoltaism according to spatial contexts. (iii) Lastly, with the same perspective of analysing agrivoltaism development trajectory through an approach based on *geography sustainability transitions*, the long-term monitoring of its deployment would allow us to analyse whether the dynamics of governance and negotiation at a local level influence the agrivoltaism framework on a national scale, and thus reveal whether *niche* dynamics influence *the regime*.

Author contributions

Analysis, writing, and editing: RC and XADS. All authors have agreed to the published version of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The authors confirm that the empirical data and materials from the study support the findings and are available within the paper. The transcripts of

all interviews are available in Norwegian and can be accessed from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
The interviewers provided verbal consent to participate in the study and were informed that they could withdraw at any time.

Competing interests
The authors declare that they have no competing interests.

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